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Technical Report ARAEW-TR-08017

SIMULATED PROOF TESTING OF MORTAR BASEPLATES

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October 2008

ARMAMENT RESEARCH, DEVELOPMENT AND ENGINEERING CENTER
Weapons & Software Engineering Center
Benét Laboratories

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
15-10-2008

2. REPORT TYPE
FINAL

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
SIMULATED PROOF TESTING OF MORTAR BASEPLATES

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Andrew G. Littlefield* and Joseph Sibilia

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army ARDEC
Benet Laboratories, RDAR-WSB
Watervliet, NY 12189-4000

8. PERFORMING ORGANIZATION REPORT NUMBER
ARAEW-TR-08017

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army ARDEC
Benet Laboratories, RDAR-WSB
Watervliet, NY 12189-4000

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSORING/MONITORING AGENCY REPORT NUMBER

12. DISTRIBUTION AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
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15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
U/U	U	U	U	12	Andrew Littlefield

19b. TELEPONE NUMBER (*Include area code*)
518-266-3972

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Abstract

In the current environment there is a need to get material to the field faster and cheaper than ever before. This is leading to an emphasis on simulation instead of live fire testing. Additionally statistical methods are being employed to use sampling instead of full lot testing. Care must be taken in employing these methods though to ensure that the final product is as good if not superior to that obtained by traditional methods. This paper will present a method of simulated proof testing of mortar baseplates that is not only delivering high quality baseplates to the field in a timely fashion but is also saving large amounts of funding while doing so.

Contents

Introduction

The increased use of mortars in current conflicts has placed a high priority in getting mortar baseplates to the field. To ensure that the baseplate is safe for use in the field it must be proof tested. In proof testing the baseplate is subjected to proof load which is greater than any load it should see in service. If the baseplate survives this load then it is considered safe for use.

Traditionally proof testing has been carried out on all baseplates via live fire testing. There are a number of reasons why this is not desirable. First is that the proof site is not collocated with the production site, Watervliet Arsenal (WVA), so large numbers of plates must be boxed, shipped to the proof site and any plates that fail must be returned to WVA. Second is availability and response time for the proof site. Higher priority workload, such as ammunition lot acceptance testing could cause proof testing to be delayed. Additionally weather conditions can often cause delays. Third is that every round that is used for proof testing is a round that is no longer available for use in the field. Finally and most importantly is the cost. The proof site's costs can vary greatly due to quantity and workload but have historically been about $2350 per plate, not including transportation or ammunition.

To overcome these issues WVA approached Benét to investigate a way to simulate proof firing. For many years Benét had investigated different ways of simulating the firing loads for a mortar baseplate utilizing pile drivers, including trying a full fatigue test. Though no work had been done on simulating a single hit proof test, this previous work provided an invaluable starting point.

There are four mortar systems for which baseplates must be proof tested. The M224 is a 60mm system used for light forces and uses the M7 and M8 baseplates. The M252 is also for light forces but is an 81mm system and uses the M3A1 baseplate. The M120 and M121 are 120mm systems that both use the M9 baseplate. This system is either towed or carrier mounted. More publicly available information can be found online (PM Mortars, 2008; US Army 2008). Figure 1 shows each of these mortar systems.

For each of these systems a different load is required. The load can vary from 14.5 kips for the M8 to 252 kips for the M9. Additionally they vary in size from 8 x 10 inches for the M8 to almost 36 inches in diameter for the M9. Any method developed had to cover this range of conditions. This paper will cover the method developed and how it was applied to each of the baseplate types.

Figure 1 – Mortar Systems (l – r) M224, M252, M120 (US Army, 2008)

Method Development and Hardware

Benét has been dynamically simulating firing loads on breech components since the 1960's for fatigue testing. These loads have been imparted through the use of pile drivers. The pile drivers have been used to compress hydraulic fluid which imparts the load to the breech ring / block. In the 1970's and 1980's (O'Hara, 1980) attempts were made to perform fatigue tests on baseplates. This work is what was used as a starting point. Old hardware and drawings were found and used to design the new hardware required.

Instead of using an actual round the firing load is imparted hydraulically through the use of pile drivers. There are two pile drivers that are available for use. The first is a Vulcan 06 hammer which drops a 6500 lb mass from up to 3 ft and the second is a Vulcan 512 which drops a 12000 lb mass from up to 5 ft.

The falling weight impacts a piston which pressurizes a fluid chamber. This fluid chamber then moves a second piston which drives the dogbone into the baseplate. The dogbone is an instrumented solid piece of steel that records the load being delivered to the baseplate. It is called a dogbone because of its appearance with a ball at each end. This test setup can be seen in Figure 2.

This fluid chamber provides a break in the mechanical load train. If the desired load can not be achieved through adjusting drop heights then the piston size can be changed. Also a fluid with a different compressibility could be used to change the response of the system.

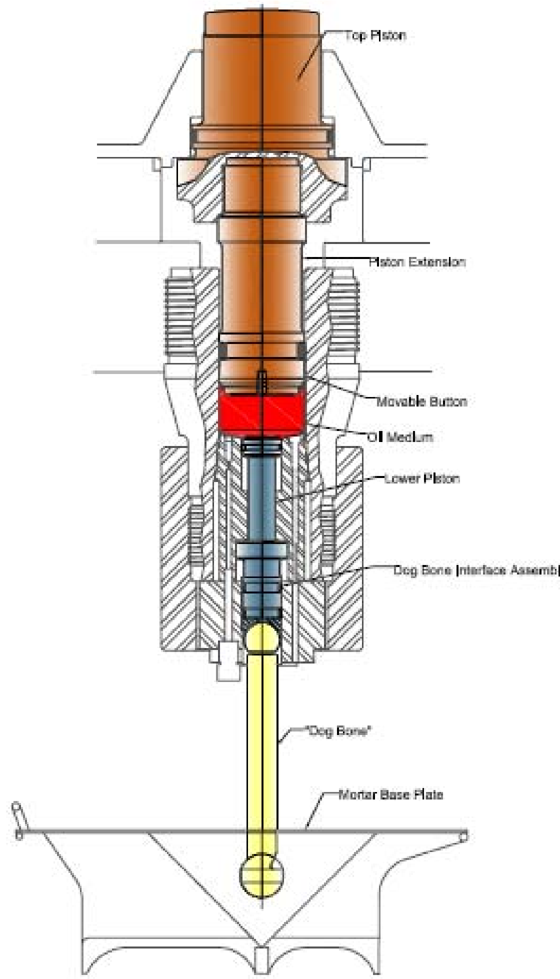

Figure 2 – Test Setup

In a fatigue test the weight is dropped via a cam bar. The weight is raised by air and trips a cam. The cam opens a valve to release air and cause the weight to fall. As the weight falls the cam then closes the valve preparing for the next cycle.

The problem with the cam bar operation though is that it only offers limited control on drop height. You need a different cam bar for each drop height and even then you need a minimum travel to trip the cam bar. For the M9 baseplate a full height drop with the 512 hammer was required but the other baseplates required a finer control so a different mechanism was required.

The load for the M8 baseplate is so small that even using the smaller 06 hammer the drop height was only about 1 in. out of the 3 ft travel. For the M7 the drop height is several inches on the 06 but less than an inch when using the 512. To make these small drops possible adjustable physical stoops were used. Bars were fabricated to stop the hammer at a preset height. Threaded feet and or shim stock was used to fine tune the drop height. The air valve was then triggered via a pneumatic actuator once the weight contacted the stops. Since air is constantly entering the hammer, the amount of time between the weight touching the stops and air release can influence the impact energy. To minimize this care was taken to ensure that the time between touching the stops and air release was consistent.

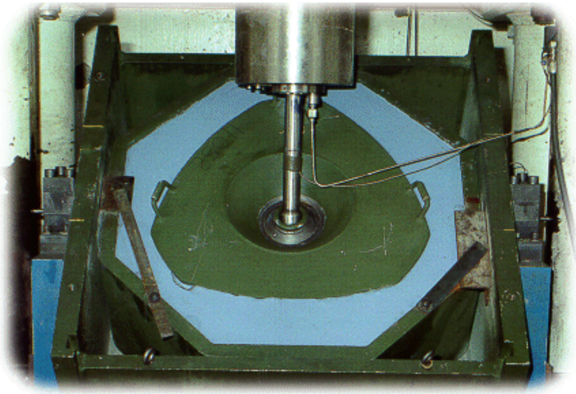

Figure 3 – M9 Baseplate Setup

Figure 4 – M8 Baseplate Setup

The ground condition was simulated with GE Silicones RTV664 rubber. This rubber had been shown to appropriately match the soil conditions used for proof testing. The baseplate is placed into an octagon shaped RTV mold which is then mounted in a gondola. The octagon mold allows for different orientations of the baseplate to be tested if required. The gondola can tip so that different loading angles can be tested if required. To counteract the load going into the building / ground the entire assembly is located in a seismic mass. An M9 baseplate is shown ready for proof testing in Figure 3.

Given the size differences in the baseplates different size octagon were required. The octagon for the M9, as shown in Figure 3, fills the entire gondola. For the smaller baseplates a smaller octagon was used. Spacers were fabricated to keep the octagon centered and the top at the correct height. Figure 4 shows an M8 baseplate ready for proof testing for comparison. The spacers can be seen around and under it. The M7, M8, and M3A1 baseplates all use the smaller octagon.

It is very important that when the mold is poured the baseplate is correctly located in the gondola. That is with its socket centered front to back, side to side, and its centerline vertically aligned with that of the gondola's trunnion bearings. This ensures that when the gondola is tipped the load is imparted vertically into the plate. Any misalignment can damage the baseplate and or buckle the dogbone.

Since the four baseplates are used with three different mortar tubes they have different socket configurations. A dogbone had to be fabricated for each configuration. To minimize changes in the setup the dogbones were all made to the same length and the same upper ball, only the lower ball that interfaces with the socket was changed. Additionally an interchangeable dogbone was created. This had screw on lower balls to match each socket. The dogbones can be seen in Figure 5.

Figure 5 – Dogbones – (from top) 120mm, 81mm, 60mm

The dogbones are the primary way of measuring the load imparted to the baseplate. They are instrumented with a four strain gages to remove any bending and record only axial strain. To convert this strain into a load the dogbones are calibrated in a press. The press applies a known axial compressive load and the strain is recorded. The dogbones were designed to respond linearly over their working range so a two point calibration will generate a value for $lb_f / \mu\varepsilon$.

Figure 6 – M3A1 Baseplate with Strain Gages

Besides the dogbone, the only other sensor used is a pressure transducer mounted in the fluid chamber. This pressure times the area of the lower pressure should give the load going into the plate. However this is not always the case.

Verification and Prove Out

To ensure good agreement with traditional proof testing one of each type of baseplate was proofed in the normal way. Each baseplate was instrumented with strain gages on both the top and bottom and crush gages were placed in bore of the cannon tube to record pressure. Figure 6 shows an M3A1 baseplate ready for proof firing. The baseplates were then put through the normal proof firing process. This firing data was then used as the baseline to compare the simulation against.

A proof firing for a baseplate consists of more than simply firing a proof round. First the tube is centered on the bipod, elevated to 45 degrees, and several seater rounds are fired to ensure that the baseplate is emplaced in the ground properly. Then three rounds are fired at one zone below maximum charge. Then the tube is traversed full right and three rounds are fired at the maximum zone. Then the tube is brought back to center and three proof charges are fired. The proof charges are in excess of the maximum zone charge. How much depends upon the system. Then the tube is traversed full left and three maximum zone charges are fired. Finally the tube is brought back to center and three more proof rounds are fired. So for a single proof test 18 rounds are fired.

The load due to firing pressure on the end cap of the mortar was calculated. The simulation uses this calculated load and imparts it onto the baseplate instead of using firing pressure. Each tube saw six proof charges so an average between the six was taken. This was then the goal of the simulated proof test with the window of acceptable load being the upper and lower loads seen during the proof rounds.

To ensure agreement with traditional proof firing the same baseplates used for the proof firing were used to prove out the simulated proofing. The plates were placed in the mold in the same orientation as during the proof firing and the strain gages were hooked up. The drop height was adjusted until the load was reliably within the range seen during the proof firing and the strains were recorded. These strains were then compared to the ones from proof firing and found to be in suitable agreement.

An interesting phenomenon was observed during the testing. It is normal to see multiple hits during a hammer test as the weight comes to a rest. These later hits normally decrease in amplitude, however when using the 06 hammer the second hit was substantially higher than the first. The duration of the pulse was shorter but the amplitude was higher by as much as 50%. This higher load though was only seen by the dogbone and not by the pressure transducer in the fluid chamber.

An investigation of the load trace showed that it changed sign between the first and second pulse. This gave an indication that the dogbone may have been in free flight. A high speed camera was used to monitor the impact of the weight and the top piston. This video was then synchronized with the dogbone data and it was clear that the second pulse occurred when the weight was no longer in contact with the top piston.

These two pieces of data led to the following conclusion as to what the sequence of events was. The weight impacts the top piston compressing everything as desired and loading the baseplate. Then due to the low mass of the weight it rebounds off of the top piston. However this is transpiring while everything below the fluid chamber is still moving downwards. This reduces the pressure in the fluid chamber and begins to pull the lower piston upwards. The baseplate and dogbone finally bottom out and the rubber rebounds. This pushes the dogbane upwards. Ideally the preload pressure in the fluid chamber should have kept the dogbone in contact with all the parts above it but the early rebound of the weight causes separation. Therefore the dogbone instead of pushing against the upper components briefly entered free flight and impacted them. The baseplate rebounds directly behind the dogbone and catches it at or just before impact.

Given the high load associated with this second pulse a decision had to be made as to which pulse to control off of. Though its pulse width was shorter than the first pulse it was still long enough to be considered. The strain gage data was checked and the baseplate was seeing this load so it was decided to control off of the second pulse. This behavior is seen with the 512 hammer as well but the heavier weight means that it takes longer for the weight to reverse direction and the resulting pulse width is so short that it was decided to control off of the primary hit.

Schedule and Cost Impact

Simulated proof testing at Benét has several advantages over traditional proof testing. First, collocation with WVA allows for quick turnaround on testing, repairs, and logistics. Secondly, As an R&D facility, Benét places priority on items in production which ensures that the baseplate simulation testing does not cause delays in production schedules. A third advantage to simulation testing is that the tests are conducted inside which removes any potential delays caused by the weather. Due to these factors lead times for testing baseplates have decreased significantly. Benét can complete baseplate simulation generally within days with the potential of same day turnaround, while depending on schedules of live proof firing can take up to months to complete.

Most importantly, testing at Benét is on average substantially cheaper. Current costs for testing baseplates range from $600 - $900 per plate. On average this is a savings of well over $1000 per plate for the almost 400 baseplates tested to date. Additionally the repeatability of the simulated test allows sampling rates as high as 1 in 5, depending upon the baseplate type. From the sampling rates and lower cost of the testing this process has saved approximately $2.3 million. This assumes $2000 for live fire testing per plate and accounts for set up costs for the simulation apparatus.

The first type of baseplate to undergo simulated proof testing was the M9. This was done because the baseplate is a weldment and collocation allowed for quick repairs of any baseplates failing proof. The success of this effort has lead to simulated proof testing of the M7, M8, and M3A1 baseplates starting in Oct of 2007.

Conclusion

A method of simulated proof testing of mortar baseplates has been developed and shown to work. In the first six months of testing, 147 M7 and 192 M8 plates have been proofed. Sampling has allowed for qualification of another 412 plates. Total cost savings for the effort is over $1.4M. At present all mortar baseplates manufactured at the Watervliet arsenal are scheduled to undergo simulated instead of traditional proof testing. This will result in plates being delivered to the field in a timely and cost effective manner.

The next phase of the effort will focus on streamlining the effort to increase throughput and consistency. Additionally an effort is currently underway to automate the hammers so that the control system will automatically control the drop height. This will eliminate the need for physical stops, allow for easy changeover to fatigue testing and more reliable results.

Acknowledgements

The authors would like to acknowledge Jake Peart and the Watervliet Arsenal for approaching us with the idea and providing the funding required. Without their help and support this effort could never have been completed.

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